SEISMIC HAZARD ZONE REPORT 127

PRELIMINARY

SEISMIC HAZARD ZONE REPORT FOR THE HONKER BAY 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

2018

DEPARTMENT OF CONSERVATION
California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the map of *Seismic Hazard Zones* for the Contra Costa portion of the Honker Bay 7.5-Minute Quadrangle (study area). Seismic Hazard Zones are a subset of *Earthquake Zones of Required Investigation (*EZRI), along with *Earthquake Fault Zones*. The topographic quadrangle map, which covers approximately 81.5 square kilometers (31.5 square miles) at a scale of 1:24,000 (41.7 mm = 1,000 meters; 1 inch = 2,000 feet), displays EZRI boundaries for liquefaction and earthquake-induced landslides. The study area includes part of the City of Pittsburg and unincorporated areas of Contra Costa County.

This Seismic Hazard Zone Report describes the development of the Seismic Hazard Zones for the Contra Costa County portion of the Honker Bay 7.5-Minute Quadrangle (study area). Ground motion calculations used by California Geological Survey (CGS) exclusively for regional zonation assessments are currently based on the probabilistic seismic hazard analysis (PSHA) model developed by the United States Geological Survey (USGS) for the 2014 *Update of the United States National Seismic Hazard Maps*.

The zonation process for liquefaction hazard includes an evaluation of ground motions, highest historical groundwater, Quaternary geologic mapping, and geotechnical data. Approximately 25square kilometers (10 square miles) of land in the study area has been designated as EZRI for liquefaction. These zones are mainly located in lowlands adjacent to Suisun Bay and New York Slough, in bedrock canyons that extend from the upland hills towards the lowlands, and, within Browns Island. Additionally, liquefaction encompass major stream valleys such as Mount Diablo Creek, Willow Creek, Kirker Creek, and other smaller unnamed stream valleys. Minor drainages that ultimately outlet into Suisun Bay are also zoned.

The zonation process for earthquake-induced landslide hazard includes an evaluation of ground motions, landslide mapping, slope gradient, rock strength, and geologic structure data. Approximately 4 square kilometers (2 square miles) of land in study area has been designated as EZRI for earthquake-induced landslides.

City, county, and state agencies are required by the California Seismic Hazards Mapping Act to use the Seismic Hazard Zone maps in their land-use planning and permitting processes. They must withhold building permits for sites being developed within EZRI until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers of real property within these zones to disclose that fact at the time such property is sold.

INTRODUCTION

The California Seismic Hazards Mapping Program

The Seismic Hazards Mapping Act of 1990 (the Act) (Public Resources Code, Division 2, Chapter 7.8) directs the State Geologist to prepare maps that delineate Seismic Hazard Zones for liquefaction, earthquake-induced landslides, tsunami inundation, and other ground failures. These are a subset of Earthquake Zones of Required Investigation (EZRI), which also include Earthquake Fault Zones. The California Geological Survey (CGS) prepares EZRI following guidelines prepared by the California State Mining and Geology Board (SMGB). For liquefaction and landslide hazard zone delineation, the SMGB established the Seismic Hazard Mapping Act Advisory Committee to develop guidelines and criteria for the preparation of seismic hazard zones in the state. The committee's recommendations are published in CGS Special Publication 118, which is available on online at: http://www.conservation.ca.gov/cgs/publications/sp118.

The purpose of the Act is to reduce the threat to public safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. City, county, and state agencies are directed to use the Seismic Hazard Zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. State-of-the-practice evaluation and mitigation of seismic hazards are conducted under guidelines published in CGS Special Publication 117A, which are available online at: http://www.conservation.ca.gov/cgs/publications/sp117a.

Following the release of the Special Publication 117A Guidelines, local government agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction and earthquake-induced landslide hazards. These agencies convened two independent committees, one for liquefaction and one for landslides, to provide more detailed procedures for implementing the Special Publication 117A Guidelines. The reports produced by these committees were published under the auspices of the Southern California Earthquake Center (SCEC) and are available online at: http://www-scec.usc.edu/resources/catalog/hazardmitigation.html.

Methodology and Organization of this Report

Delineating liquefaction and earthquake-induced landslide hazard zones requires the collection, compilation, and analysis of multiple types of digital data. These data include geologic maps, ground water measurements, geotechnical data, elevation (terrain) maps, and probabilistic ground motion estimates. The data are processed into a series of geographic information system (GIS) layers using commercially available and open-source software, which are used as input for the delineation of hazard zones.

Earthquake Zones of Required Investigation (EZRI) for liquefaction and earthquake-induced landslides share many input datasets. Section 1 of this report describes the geographic, geologic, and hydrologic characteristics of the Contra Costa County portion of the Honker Bay Quadrangle (study area) and laboratory tests used to categorize geologic materials within the quadrangle according to their susceptibility to liquefaction and/or landslide failure. Section 2 describes the development of the earthquake ground motion parameters used in the liquefaction and earthquake-induced landslide hazard analyses, presents map plates of the spatial distribution of key ground motion parameters, and summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential in the Honker Bay Quadrangle. Sections 3 and 4 summarize the analyses and criteria used to delineate liquefaction and earthquake-induced landslide hazard zones, respectively, in the study area.

Scope and Limitations

Seismic Hazard Zones for liquefaction and earthquake-induced landslides are intended to prompt more detailed, site-specific geotechnical investigations. Due to scale, and other limitations inherent in these zones, they should not be used as a substitute for site-specific geologic or geotechnical investigations required under Chapters 7.5 and 7.8 of Division 2 of the California Public Resources Code. Site-specific geologic/geotechnical investigations are the best way to determine if these hazards could affect structures or facilities at a project site.

The Seismic Hazard Zones described in this report identify areas where the potential for ground failure related to liquefaction and earthquake-induced landslides is relatively high. Some liquefaction and earthquake-induced landslide occurrences may occur outside the delineated zones in future earthquakes, but the majority of the occurrences should be within zoned areas. Conversely, not all of the area within a hazard zone will experience damaging ground failure in future earthquakes. The analyses used to delineate liquefaction and earthquake-induced landslide zones cannot predict the amount or direction of liquefaction- or landslide-related ground displacements, or the amount of damage to structures or facilities that may result from such displacements. Because of this limitation, it is possible that run-out areas during future earthquakes could extend beyond zone boundaries.

Other earthquake-induced ground failures that are not specifically addressed in the analyses conducted for the study area include those associated with soft clay deformation, non-liquefaction-related settlement, ridge-top spreading, and shattered ridges.

Although data used in this evaluation was selected using rigorous criteria, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Accessing Earthquake Zones of Required Investigation Maps, Reports, and GIS Data

CGS EZRI, including Seismic Hazard Zones and Earthquake Fault Zones, their related reports and GIS data, are available for download and/or online viewing on the CGS Information Warehouse: http://maps.conservation.ca.gov/cgs/informationwarehouse/.

Alternatively, EZRI are available as an interactive web map service (WMS) here: https://spatialservices.conservation.ca.gov/arcgis/rest/services/CGS_Earthquake_Hazard_Zones.

EZRI are also available on a statewide parcel base, which can be useful for initial Natural Hazards Disclosure determinations, by using the California Earthquake Hazards Zone Application (EQ Zapp): https://maps.conservation.ca.gov/cgs/EQZApp/app/.

EZRI maps and reports are also available for purchase at the CGS Sacramento office at the address presented below, or online at: http://www.conservation.ca.gov/cgs/publications/shop.

Publications and Information Office
801 K Street, MS 14-34
Sacramento, CA 95814-3531
(916) 445-5716

Information regarding the Seismic Hazard Zonation Program with links to the Seismic Hazards Mapping Act and the Alquist-Priolo Earthquake Fault Zoning Act are available on the CGS website: http://www.conservation.ca.gov/cgs/shp.

SECTION 1: GEOGRAPHY, GEOLOGY AND ENGINEERING GEOLOGY

of the

HONKER BAY 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

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Purpose of this Section

Preparing Earthquake Zones of Required Investigation (EZRI) for liquefaction and earthquake-induced landslides requires many input datasets and complex analyses. The purpose of Section 1 of the Seismic Hazard Zone Report is to describe the overall geologic and geographic setting of the Contra Costa County portion of the Honker Bay Quadrangle (study area) and then discuss the collection, processing, and analyses of primary geologic and engineering geologic data that were used to delineate EZRI.

GEOGRAPHY

Location

The study area covers an area of approximately 81 square kilometers (31square miles) in eastern Contra Costa County, California. The center of the study area is about 38 kilometers (24 miles) northeast of the City of Oakland and about 73 kilometers (45 miles) south-southwest of the City of Sacramento. The study area includes the central and northwestern portion of the of City Pittsburg, unincorporated areas of Contra Costa County, and a small northeastern portion of the City of Concord. Unincorporated areas in the study area include the communities of Shore Acres and West Pittsburg (renamed Bay Point). The Concord Naval Weapon Station is completely within the limits of the city.

The study area is located south of the confluence of the San Joaquin and Sacramento Rivers, and along the southern shores of Suisun Bay. The study area is located on the northeastern end of the Los Medanos Hills, part of the Diablo Range in the Coast Ranges Geomorphic Province (Schemmann and others, 2007; Weber-Band, 1997). Elevations in the map area gradually increase from sea level along the shores of Suisun Bay to just over 300 meters (980 feet), along the south-central boundary of the study area. The general topography consists of mild sloping Pittsburg-Antioch and Clayton Valley alluvial plains emanating from the Los Medanos Hills.

In the northeastern part of the study area, water flows north to northeast in the drainages of Lawlor Ravine, Willow Creek, Kirker Creek, and several unnamed streams from the Los Medanos Hills, across the Pittsburg-Antioch alluvial plain, and outlet into Suisun Bay. In the southwestern part of the study area, water flow west to northwest in the drainage of Mount Diablo Creek from the Los Medanos Hills, across the Clayton alluvial plain, and ultimately outlets into Suisun Bay.

Portions of the Contra Costa Canal (Main Canal segment) and Mokelumne Aqueduct traverse the central part of the study area, and flow east to west. These man-made water conveyance systems provide water for agricultural, industrial, and municipal uses in the Bay Area. The Contra Costa Canal was built in 1948 and diverts Sacramento-San Joaquin Delta water from Rock Slough in the east to Martinez in the west (CCWD, 2009). Water in the Mokelumne aqueduct is sourced from the Mokelumne River and provides water to the eastern Bay Area. A portion of the Clayton Canal traverses the southwest corner of study area within the Concord Naval Weapons Station. Clayton Canal is abandoned and currently collect storm water runoff and drain into Contra Costa Canal (Loop Canal segment).

Land Use

Land use in the study area was historically dominated by agriculture in flatland areas and ranching in the surrounding low-lying hills. Following the discovery of coal in the nearby town of Nortonville in the 1850's, Pittsburg became a regional port for coal, which was the first substantial industry aside from farming in the area (Durham, 1998). After coal operations ceased in the early 1900's, steel manufacturing became the main industrial driver in the northern part of the study area (Heredia, 1999). In the southwestern portion of the study area, the Concord Naval Weapons Station opened in 1942 and remained operational until 2005 when the Defense Base Realignment and Closure Commission announced that the Inland Area of the base was approved for closure (Defense Base Realignment and Closure Commission, 2005). In the last several decades, urban development substantially increased in the City of Pittsburg and communities of Bay Point and Shore Acres with light industrial, shopping centers and home construction. Since 1990, Pittsburg has grown by 50% with development largely occurring to the south into the foothills and west of the city center towards Bay Point. Substantial areas of undeveloped land remain in the study area, primarily along the shoreline of Suisun Bay and in the uplands of the southern part of the quadrangle. Most of the undeveloped uplands in the southern part of the map area are included in the Concord Hills Regional Park, operated by the East Bay Regional Park District.

The primary automotive transportation route in the study area is California State Route 4, which trends east-west through the central part of the study area, connecting the City of Pittsburg with the cities of Antioch and Concord. Railway routes within in the study area include the Atchison-Topeka and Santa Fe, Southern Pacific, and BART railways in the north and central parts of the study area. Kirker Pass Road and Bailey Road are major north-south thoroughfares that traverse the Suisun Hills and connect the City of Pittsburg with the cities of Concord and Clayton. Willow Pass Road traverses the northern part of the study area and provides access between unincorporated places Bay Point and Shore Acres. Loveridge Road, Leland Road, Buchanan Road, and Harbor Street are thoroughfares that traverse the suburbs of southern Pittsburg. Access to undeveloped areas within the quadrangle is primarily by paved county roads and paved and unpaved private roads south of the City of Pittsburg.

Digital Terrain Data

A digital representation of the earth's surface is a key component in delineating liquefaction and earthquake-induced landslide hazards. Within the study area, digital topography in the form of a DEM obtained from Contra Costa County (http://www.co.contra-costa.ca.us/4475/Maps-and-Data). This terrain data was collected in 2010 and presents point spacing of 3 meters and elevations at 1-meter horizontal accuracy and 15-cm RMSE vertical accuracy.

For liquefaction hazard analyses, surface elevations derived from the Contra Costa County DEM are differenced with historic-high ground water elevations to derive a "depth to water" map. In alluvial areas, the depth value obtained was analyzed, along with geologic data from boreholes and used in liquefaction evaluation.

For earthquake-induced landslide hazard analyses, slope gradient and slope aspect maps were made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). Slope gradient and geologic strength are the main parameters used in the earthquake-induced landslide stability analyses. Slope aspect, the compass direction that a slope faces, is used to identify potential adverse geologic bedding conditions and thereby refine geologic material strength maps. The slope map was used with the geologic strength map in the preparation of the landslide hazard potential map.

GEOLOGY

The primary sources of geologic information used in the evaluation of liquefaction and earthquake-induced landslide hazards in the Contra Costa County portion of the Honker Bay 7.5-Minute Quadrangle (study area) is the California Geological Survey (CGS) unpublished preliminary geologic map digital database of the Lodi 30' x 60' Quadrangle (Dawson, 2010). This bedrock geologic map was compiled from detailed and regional geologic mapping by Witter and others (2006), Knudsen and others (2000), Knudsen and Lettis (1997), Graymer and others (1994 and 1996), and Bartow (1985). Additional geologic maps and reports reviewed for the Quaternary sedimentary deposits include 1:24,000-scale geologic mapping by Witter and others (2006), Knudsen and others (2000), Helley and Graymer (1997), Dibblee (1980), and Nilsen (1975).

Digital geologic maps covering the study area and adjacent areas were combined to form a single, 1:24,000-scale, geologic materials map. CGS staff used DEMs, aerial photos, online imagery, and limited field reconnaissance to modify the Quaternary/bedrock boundary, confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the newly created landslide inventory would exist on separate layers for the hazard analysis. Young alluvial valleys were added or modified by CGS geologists in some areas to refine the map and ensure continuity of geologic mapping with adjacent quadrangles. Linear structural features such as folds, faults, and anticlines that did not form a geologic boundary were removed. Young alluvial valleys were added or modified by CGS geologists in some areas to refine the map and ensure continuity of geologic mapping with adjacent quadrangles. The distribution of Quaternary and bedrock deposits on the final geologic materials map was used, in combination with other data, to evaluate liquefaction and landslide susceptibility and develop the Seismic Hazard Zone Map.

The following bedrock unit nomenclature, and the descriptions of geologic units exposed in the study area, are taken primarily from Dawson (2010). The following Quaternary geologic unit nomenclature used by CGS for mapping in the San Francisco Bay Region was adopted from Knudsen and others (2000).

Bedrock Units

The bedrock geology of Contra Costa County has been divided by Graymer and others (1994) into six individual stratigraphic assemblages, each lying within a discrete, fault-bounded block. The concept of individual fault-bounded stratigraphic assemblages in the San Francisco Bay Area was introduced by Jones and Curtis (1991) and then defined further by Graymer and others (1994). These investigators believe that the individual stratigraphic assemblages originated in separate depositional basins or in different parts of large basins that were later juxtaposed by large offsets on strike-slip and dip-slip faults during Tertiary time. Stratigraphic assemblage VI underlies the entire Honker Bay Quadrangle (Graymer and others, 1994).

In Contra Costa County, the oldest rocks exposed in the fault-bounded assemblages belong to two slightly to highly deformed Mesozoic rock complexes: The Jurassic Coast Range Ophiolite and overlying Cretaceous Great Valley Sequence, and the Jurassic to Cretaceous Franciscan Complex (Graymer and others, 1994). These units are not exposed in the study area, but underlie the Tertiary and younger units exposed in this study area. The Tertiary units exposed in the study area consists of a thick sequence of non-marine to marine interbedded sandstone, shale, and volcanic deposits that have been folded, faulted and uplifted (Graymer and others, 1994).

An angular unconformity forms the boundary between the underlying Cretaceous Great Valley Sequence units and Tertiary marine strata exposed in the study area (Graymer and others, 1994). Tertiary rocks belonging to stratigraphic assemblage VI outcrop in the study area where they have not been buried beneath Quaternary sediments (Plate 2.1). The following is a summary of bedrock map units exposed in the study area based on Dawson (2010).

Tertiary Bedrock Units

The uplands in the southern quarter of the study area are covered by Tertiary rocks. These rocks are expressed in narrow to wide linear outcrops that typically dip to the north or northeast and become younger to the northeast. The Tertiary units consist of a series of sandstone, shale, conglomerate, and tuff formations that range from Eocene to Pliocene in age and are exposed along a northwest-southeast trending band in the southern part of the study area. At their eastern extent, these bedrock units form moderately steep slopes with narrow north-south trending valleys and drainages. However, in the western part of the study area these units have variable topographic relief and ridge morphology, and no consistent drainage pattern. Many of these units have been subjected to extensive grading and development and topographic expression of the members have been significantly altered.

The Markley Formation is the oldest and most prominent bedrock unit in the study area, covering approximately 40% of the uplands. It is exposed along the southwestern boundaries of the study area and is divided into an upper member (**Emku)** and a lower member (**Emkl)**. The Upper Member of the Markley Formation consists of a white- to light-gray and brown, thin-bedded mudstone, siliceous mudstone, siltstone, and quartz-muscovite sandstone. The lower member is a thin-bedded to massive quartz-muscovite sandstone with minor siltstone and mudstone beds. In most of the study area the Markley Formation is in conformable contact with the overlying late Miocene Cierbo Sandstone (**Mc**). However, in the southwest part of the study area, the Markley Formation is in unconformable fault contact with the Lawlor Tuff (**Plt**) and the Tehama Formations (**Pth**).

The Cierbo Sandstone (**Mc**) occurs as a light gray, clean, white marine sandstone that is fine-to coarse-grained and moderately consolidated. Locally, the marine sandstone contains beds of fossiliferous sandstone and minor pebble conglomerates near the base. It is conformably overlain by the late Miocene Neroly Formation (**Mnr**) in the south-central and southeastern part of the study area and in unconformable contact with the overlying Lawlor Tuff (**Plt**) in the southwestern part of the study area. The overlying Neroly Sandstone (**Mnr**) consists of blue to gray, fine to coarse-grained, volcanic-rich, shallow marine sandstone, with minor gray and brown siltstone, shale, tuff and andesite-pebble conglomerate layers. It is best exposed along trails in Stoneman Park in the south-central part of the study area. Unconformably overlying the Neroly Sandstone is the Pliocene Lawlor Tuff (**Plt**), a Sonoma Volcanics derived light-gray Plinian pumice-fall and unwelded, pink to light-brown, pumice-ash-flow unit. The Lawlor Tuff attains a maximum thickness of 15 meters near Port Chicago Highway and has an Ar/Ar age of 4.83 ± 0.04.

The youngest non-Quaternary unit in the study area, the Pliocene Tehama Formation (**Pth**), is a poorly consolidated, non-marine, gray to maroon siltstone, sandstone, tuff, and weakly indurated pebble to cobble conglomerate. Clasts in the Tehama Formation are composed mainly of greenstone with lesser quantities of metamorphic fragments, chert, and occasional granitic rock fragments. The northern margins of the Tehama Formation in the study area have has undergone extensive grading, and minimal topographic relief of the unit remains in some areas.

Quaternary Sedimentary Deposits

Within the study area approximately 38 km^2 (15 mi^2) are covered by Quaternary sediments, of which approximately 21 km^2 (8 mi^2) are latest Pleistocene to Holocene age (Plate 1.1). These sedimentary units are summarized in Table 1.1 and discussed below. The following is a summary of Quaternary sedimentary deposits exposed in the study area is based on Dawson (2010); Witter and others, (2006), Knudsen and others (2000); Helley and Graymer (1997); Dibblee (1980), and Nilsen (1975).

Table 1.1. Quaternary units mapped in the Contra Costa County portion of the Honker Bay Quadrangle.

CGS Map Units	Dawson, 2010 (1:100,000)	Witter and others, 2006 (1:24,000)	Knudsen and others, 2000 (1:24,000)	Helley and Graymer, 1997 (1:24,000)	Dibblee, 1980 (1:24,000)	Nilsen, 1975 (1:24,000)	Environmental Deposition	Age
Qpf	*Qf Qpf*	*Qof Qpf Qoa?*	*Qf Qpf*	*Qpaf*	*Qoa*	*Qt*	Old Fan, Alluvium deposits, Terraced deposits	Pleistocene to Holocene
Qhf	*Qhf Qhff Qhl*	*Qhf Qht Qha*	*Qhf Qhff Qhl*	*Qhaf Qhb Qhl*	*Qa*	*Qal*	Alluvial Fan Deposits	Holocene
Qhbm	*Qhbm*	*Qhbm*	*Qhbm*	*Qhbm*	*Qbm*	*Qm Qsl*	Bay Mud, Marshland and Slough deposits	Holocene to Modern
Qhsc	*Qhc*	*Qhc*	*Qhc*	*Qhsc*	*Qa*	*Qal*	Stream Channel Deposits	Holocene to Modern
af	*ac afbm alf*	*af adf alf afem ac acf*	*ac afbm alf*	*af alf Qhasc*		*Qaf Qsl*	Artificial Fill, Artificial Fill over Bay Mud, Artificial Levee Fill, Slough deposit, Artificial dam fill, Artificial Stream Channel	Modern

Old Quaternary Units

The oldest Quaternary unit exposed in the study area are Pleistocene alluvial fan deposits (**Qpf**), poorly-sorted to well-sorted deposits containing unconsolidated mixtures of gravel, sand, silt, and clay, with particle size typically decreasing downstream, away from the alluvial fan apex. These typically stream-deposited sediments emanated from Los Medanos Hills onto Pittsburg-Antioch and Clayton alluvial plains, and include terraced, debris flow and braided stream deposits. **Qpf** deposits are thickest adjacent to the paleo-stream channel and typically thin away from the channel axis. The deposits in the study area are spatially terraced in narrow bedrock canyons, and incised along the broad gentle-sloping fans on valley floors. Deposits of **Qpf** overlie bedrock in the study area.

Young Quaternary Units

Holocene alluvial fan deposits (**Qhf**) typically form in narrow bedrock canyons, incised within older alluvium deposits, and situated over older alluvial fan deposits on Pittsburg-Antioch and Clayton valley floors. These poorly-sorted to well-sorted deposits contain unconsolidated mixtures of sand, silt, and clay, and gravel, with particle size typically fining downstream, away from Los Medanos Hills. **Qhf** typically consist of stream-deposited or redeposited, and include debris flow, terraced, levee, and flat-floored basin deposits. **Qhf** deposits are thickest adjacent to the stream channel and typically thin away from the channel axis. Deposits of **Qhf** unconformably overlie Pleistocene alluvial fan deposits (**Qpf**) in the study area.

Holocene bay mud deposits (**Qhbm**) typically form in estuarian, tidal marsh, mud flat, or bay bottoms environments, and locally modified with diked for farming, salt evaporators, or other purposes. These well-sorted deposits contain unconsolidated mixtures of silt, clay, and fine sand, with local deposits containing organic plant matter and shells. **Qhbm** typically consist of tidal wetland sediments include peat and peaty mud deposits with sand lenses at or near sea level. **Qhbm** deposits typically thicken towards Suisun Bay and the San Joaquina River, and generally uniform on Browns and Winter Island. Deposits of **Qhbm** are conformably interlayered with overlie Holocene alluvial fan (**Qhf**), and unconformably overlie Pleistocene alluvial fan deposits (**Qpf**) in the study area

Holocene channel deposits (**Qhc**) typically form in narrow bedrock canyons, incised within alluvium deposits, and situated over older alluvial fan deposits on valley floors. These poorly-sorted to well-sorted deposits contain unconsolidated mixtures of sand, gravel, and cobble, with minor silt and clay. The particle size distribution of these deposits typically fining downstream, away from Los Medanos Hills. These typically stream-deposited or redeposited sediments are frequently reworked. **Qhc** deposits are thickest adjacent to the stream axis and thins towards the boundaries. Deposits of **Qhc** unconformably overlie Holocene alluvial fan and bay mud deposits (**Qhf** and **Qhbm**), and Pleistocene alluvial fan deposits (**Qpf**), in the study area.

Late Holocene artificial fills (**af**) typically are found in areas of recent highway and railway embankments, along the developed bay margin, and areas developed along channels or lakes. These fills are engineered and non-engineered deposits resulting from reworking of soils due to human activity. Although areas with significant fills have been mapped, not all fills are represented in the study area. The thickness of fills varies and are mostly undetermined based on lack of grading information. Local grading details including survey documentation of over-excavation and finish surface grade are beyond the limit of this study. Deposits of fill unconformably overlie Holocene alluvial fan, bay mud, and channel deposits (**Qhf**, **Qhbm**, **Qhc**), and Pleistocene alluvial fan deposits (**Qpf**), in the study area.

Geologic Structure

The structural framework of the study area is governed by the geologic processes that created Mount Diablo. This area falls within in a tectonically active region associated with movement of the Mendocino Triple Junction along the boundary of the Pacific and North American plates. The Mendocino Triple Junction passed the latitude of Mount Diablo about 10 million years ago, generating a change from a convergent to a strike slip plate boundary margin. The two plates are currently moving past each other in a right lateral sense at the rate of about 4.8 centimeters per year (Petersen and others, 1996).

In the San Francisco Bay area movement is presently accommodated by shearing that is distributed across a broad, complex belt marked by major northwest-trending faults, including the San Andreas, Hayward, and Calaveras, along with parallel secondary faults such as the Greenville, Green Valley, and San Ramon-Concord. Differential strike-slip movement among these faults locally generates thrust faulting, folding, and related structures throughout this tectonic belt. Movement on these faults has resulted in the current transpressional tectonic regime, characterized by horizontal northeast-southwest maximum compression, that has uplifted Mount Diablo and folded the surrounding rocks over the last 4 million years into the Mount Diablo Anticline (Schemmann and others, 2007) and associated Los Medanos Hills Thrust system (Weber-Band and others, 1997; Unruh and Sundermann, 2006).

The study area is located at the northeastern end of the Los Medanos Hills and contains portions of the Pittsburg-Antioch and Concord alluvial plains. The alluvial plains unconformably overlies the northeast and southwester flank of the Los Medanos Hills, which consist of a complex of northeast dipping faults that elevate the Los Medanos Hills (Weber-Band and others, 1997; Unruh and Sundermann, 2006). The northwest-southeast trending axis of the Mount Diablo Anticline passes through the core of Mount Diablo south of the study area. The Los Medanos Hills consist of a northeast dipping homocline that exposes the Tertiary strata with bedding dips ranging from 20 to 70 degrees, the majority being about 45 degrees (Unruh, and others, 2007; Weber-Band and others, 1997; Unruh and Sundermann, 2006). In the study area, the geologic units typically strike to the west-northwest and northwest with north or northeast dips typically ranging from up to about 40 degrees in the oldest units in the southwest and decreasing in the increasingly younger units toward the northeast to as low as about 12 degrees.

The northwest-southeast trending Greenville Fault Zone, Clayton Section is mapped 3 kilometers south of the study area. This fault is pre-Holocene (>11,700 years) and well constrained in bedrock and alluvium (Bryant and Cluett, 2002, Dawson, 2010 and Schemmann, Unruh and Moores, 2007). No active faults are mapped in the study area by the California Geological Survey, under the Alquist-Priolo Earthquake Fault Zoning Act.

Several Quaternary aged (<2.6 my) faults are mapped within or project towards the study area, including the Pittsburg-Kirby Hill fault zone within the northernmost portion of the study area (Graymer and others, 2006) and the Vaca fault approximately 10 kilometers (6 miles) north of the study area where it is subparallel to Kirby Hills fault (Knuepfer, 1977). The Pittsburg fault segment of the Pittsburg-Kirby Hill fault zone is mapped just east of Mallard Slough and trends northwest-southeast towards the eastern edge of the study area, between California State Route 4 and New York Slough. This segment of the fault is moderately constrained in Pleistocene alluvial fan (**Qpf**) deposits, and concealed in Holocene bay mud deposits (**Qhbm**) and by Suisun Bay. The Pittsburg fault segment joins with the Kirby Hills fault just east of Mallard Slough. The southernmost extent of the Kirby Hills fault is mapped as concealed by Graymer and others (2006) from the southern shore of Suisun Bay northward. Two unnamed northwest-southeast trending faults are mapped on the western and southwestern portions of the study area. One of the faults is mapped along southwestern base of the Los Medanos Hills, the other along the central axis of the Los Medanos Hills. These faults are relatively short in length but are well constrained in bedrock (Graymer and others, 2006). Several other unnamed, well constrained, north-south or east-west trending, apparently pre-Quaternary aged faults are mapped in bedrock in the southwest corner of the study area (Bryant and Cluett, 2002, Dawson, 2010 and Graymer, et al, 1994). No active faults are mapped in the study area are designated as Earthquake Zones of Required Investigation by the California Geological Survey, under the Alquist-Priolo Earthquake Fault Zoning Act.

Existing Landslides

As a part of the geologic data compilation, an inventory of existing landslides in the study area has been prepared through field reconnaissance, a review of previously published landslide mapping, but primarily was interpreted from geomorphic analyses of lidar derived topography and digital stereo imagery employing a GIS-based softcopy photogrammetric system (listed in the “Air Photos” section of the Reference section). The digital imagery has an approximate 0.84 meter pixel dimension that approximates the resolution of 1:30,000- to 1:40,000-scale print imagery. All landslides in this were digitized on the photogrammetric system, which has been estimated to result in features with 6-meter horizontal and 2-meter vertical accuracies. Landslide mapping was not conducted in areas of the uplands where extensive grading was conducted prior to imagery capture, as this grading likely removed the geomorphic evidence of slope instability, see Plate 2.2.

Landslides were mapped at a scale of 1:24,000. For each landslide included on the map, a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable, and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the landslide zone as described later in this report. Landslides rated as questionable were not carried into the zone map. The completed landslide map was digitized and the attributes were entered into a database. A small-scale version of this landslide inventory is included on Plate 2.1.

A total of 53 landslides were identified in the landslide inventory, covering about 10% of the uplands of the study area, or approximately 2.5 square kilometers (about 1 square mile). There are no historic landslides and the majority are dormant-mature and dormant young, consisting of 45 rockslides, 7 earth flows, and 1 debris flow. As the dip of strata generally exceeds the slope inclination, the dip slope landslides do not appear to be dip slope failures; but rather a primary controlling factor seems to be the differing geologic units and steep slopes. Landslides appear to occur where slopes are steeper with higher relief, and are larger in the south-central part of the study area. The largest mapped landslide in the study area is a dormant old/relict landslide in the lower member of the Markley Formation (**Emkl)**. The headscarp of this large landslide coincides with the location of a north-south trending pre-Quaternary fault mapped in the southern part of the study area, suggesting faulting may have played a role in slope failures in this area.

The distribution and density of landslides mapped in the study area (Plate 2.1) differ among the different geologic units, mainly as a function of areal distribution of various rock types along with variations in rock strength, topography, and structure. In the Tertiary rocks covering the uplands of the study area, landslides cover about 10% of the landscape. However, landslide coverage of the Tertiary outcrops varies dramatically, ranging from less than 1% for the Neroly Formation (**Mnr**); 5% to 10% for the Cierbo Sandstone (**Mc**), Tehema Formation (**Pth**), and Lawlor Tuff (**Plt**); and more than 15% of the outcrop area is covered by landslides for the lower member of the Markley Formation (**Emkl**).

Because it is not within the scope of the Seismic Hazards Mapping Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Historic-High Groundwater Mapping

Natural hydrologic processes and human activities cause groundwater levels to fluctuate over time, and it is impossible to predict the depths to saturated soils during future earthquakes. One method to address time-variable depth to saturated soils is to establish a high groundwater level based on historical groundwater data. In areas where groundwater is currently near the surface (within 50 feet), or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps depicting highest historical depth to groundwater surface. Plate 1.2 depicts contours reflecting the historic-high depth to groundwater surface within the Contra Costa County portion of the Honker Bay 7.5-Minute Quadrangle (study area).

Hydrographic Setting

Various parameters such as tides, precipitation, evaporation, watershed area, surface runoff, basin infiltration, and human activity influence the hydrologic setting in the study area. The margins of Suisun Bay and New York Sough define the base potentiometric groundwater surface for the groundwater basin in the study area. The regions general climate is considered Mediterranean, with annual precipitation ranging from 11 to 18 inches (CDWR, 2003). Precipitation is the primary source of water to the groundwater basin. Precipitation and evaporation is consolidated by the topographic relief in each watershed. Within the various watersheds, the concentration of surface runoff and its infiltration into the basin alter the potentiometric surface to define the groundwater surface. Human activity has further artificially modified the hydrographic setting through development, grading, and pumping.

A majority of the study area is within the Suisun Hydrologic Unit (HU) of the San Francisco Hydrologic Basin Planning Area (HBPA) defined by the California State Water Resources Control Board and (CIWMC, 2004). The Suisun HU is divided in to the Concord, Suisun Bay, and Suisun Bay - in Delta Hydraulic Areas (HAs). The Hydrologic Subareas include the Pittsburg, Pittsburg – in Delta, and other undefined areas, see Table 1.2 for a breakdown of these watershed boundaries.

Table 1.2. State of California watershed boundary designations in the Contra Costa County portion of the Honker Bay Quadrangle.

<table>
<tr><th>Hydrologic Basin Planning Area (HBPA)</th><th>Hydrologic Unit (HU)</th><th>Hydrologic Area (HA)</th><th>Hydrologic Subarea (HSA)</th></tr>
<tr><td rowspan="5">San Francisco Bay</td><td rowspan="5">Suisun</td><td rowspan="2">Concord</td><td>Pittsburg</td></tr>
<tr><td>Pittsburg
- in Delta</td></tr>
<tr><td rowspan="2">Suisun Bay</td><td>undefined</td></tr>
<tr><td>undefined</td></tr>
<tr><td>Suisun Bay
- in Delta</td><td>undefined</td></tr>
</table>

These HAs and HSAs are used to locally identify the contributions of precipitation, surface water, and groundwater inflows into the watershed within the specific portions of the groundwater basin. The historic-high depth to groundwater contour surface is typically depressed along Hydraulic Subareas (HSAs), as the boundaries represent areas of divergent surface water (USGS, 2013).

Groundwater Basins

The California Department of Water Resources (CDWR) groundwater basins within the study area includes the Pittsburg Plain Groundwater Basin (2-004), and a portion of the Clayton Valley Groundwater Basin (2-005) (CDWR, 2003). The specific groundwater basin boundaries used for this study are more detailed and defined by the best available Quaternary geologic maps, which delineate consolidated and unconsolidated sedimentary deposits in the flatlands and narrow valleys. Plate 1.2 depicts the specific basin boundaries in the study area that characterize actual or historic shallow groundwater.

In the study area, near-surface unconfined groundwater basin materials consist of Pleistocene to recent age highly lenticular alluvial deposits (CDWR, 2003). Confined aquifers have not been delineated in the study area. Natural groundwater recharge in this study area is generally from precipitation, and streambed percolation from Willow Creek, Kirker Creek, Mt. Diablo Creek, and several unnamed streams. Artificial sources of groundwater recharge may include urban landscape irrigation, agricultural irrigation, septic tanks, and other agricultural or recreational water impoundments. Additionally, artificial recharge related to small water impoundments locally raise groundwater levels downstream and upstream of the reservoir due to seepage.

Groundwater Levels

Groundwater levels in the study area were evaluated using depth to groundwater well records compiled from the Department of Water Resources (CDWR), California Water Resources Control Board (CWRCB), California Department of Transportation (CDOT), and local water districts and agencies. The groundwater well or borehole records consisted of available online data from geographic information systems, water well drilling logs, basin management plans, and groundwater monitoring reports.

Groundwater level data in this study represents more than 4,530 collected measurements from monitoring wells and borehole logs. Most of the groundwater level data is from CWRCB GeoTracker and GeoTracker GAMA websites, which contain mostly groundwater and environmental monitoring well measurements spanning a relatively narrow range of years – from 2001 to 2018 (CWRCB, 2018). Some of the groundwater level data is from CDWR and CDOT, which contain groundwater monitoring well measurements and as-encountered groundwater measurements from borehole logs spanning a wider range of years, 1960 to 2017 (CDWR, 2018; CDOT, 2018). Groundwater levels have remained stable over the period of record except for static water level drops and subsequent recovery associated with the 1976 - 1977 and 1987 - 1992 drought periods (CDWR, 2003).

Groundwater data from all available records were spatially and temporally evaluated in a geographic information system (GIS). CGS created a historic-high groundwater elevation surface for the groundwater basin of the study area based on available groundwater level data and data from previous groundwater basin studies. The highest historical groundwater elevation surface was compared with the existing ground-surface elevation (DEM), and consideration was given to active creeks, recharge ponds, detention basins, water impoundments, and reservoirs. The depth to groundwater contours depicted on Plate 1.2 do not represent present-day conditions or conditions at any specific date in time, as usually presented on typical groundwater contour maps, but rather the historic-high depths to groundwater for the basin. In areas where the historic depths to groundwater are not well constrained, usually within the upper reaches of narrow valleys and in canyons, a depth to groundwater value of less than 10 feet was assigned, unless otherwise noted. Water depth data from boreholes known to penetrate confined aquifers or screened in weathered and/or fractured rock units were not utilized in this study.

Historic-high groundwater elevation gradients within the groundwater basin are generally consistent with natural topographic gradients, which flow towards the north-northeast. It is important to note that the initiation or expansion of large-scale artificial recharge programs could significantly affect future groundwater levels. When alerted of such programs, CGS will evaluate their impact relative to liquefaction potential and revise official Seismic Hazard Zone maps, if necessary.

Geologic Material Testing

Liquefaction Hazard Zoning: In-Situ Penetration Resistance

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests in alluvial materials. The Standard Penetration Test (SPT) provides a standardized measure of the penetration resistance of geologic deposits and is used as an index of soil density. For this reason, SPT results are a critical component of the Seed-Idriss Simplified Procedure (Seed and Idriss, 1982), a method used by CGS and the geotechnical community to quantitatively analyze liquefaction potential of sandy and silty material. SPT is an in-field test based on counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials (ASTM) in test method D1586 (ASTM, 2018). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differs from that specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts, if reliable conversions can be made. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of 1 atmosphere (approximately 1 ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$. Geotechnical borehole logs provided information on lithologic and engineering characteristics of Quaternary deposits within the study area.

For liquefaction hazard zoning in the study area, borehole logs were collected from the files of the City of Antioch, City of Pittsburg, and California Department of Transportation (CDOT). Data from a total of 450 borehole logs were entered into the CGS geotechnical GIS database and analyzed.

Of the 450 geotechnical borehole logs analyzed in this study (Plate 1.3), most included blow-count data from SPTs or from penetration tests that allow reasonable blow count conversions to SPT-equivalent values. Few of the borehole logs collected, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal analysis using the Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using either recorded density, moisture, and sieve test values or using averaged test values of similar materials.

Landslide Hazard Zoning: Laboratory Shear Strength

To evaluate the stability of geologic materials susceptible to landslide failure under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the study area's geologic map were obtained from the City of Antioch, City of Pittsburg, and the California Department of Transportation. The locations of rock and soil samples taken for shear testing within the study area are shown on Plate 1.3. Shear tests from neighboring quadrangles (Antioch South, Brentwood, and Clifton Court Forebay) were used to augment data for several geologic formations for which little or no shear test information was available within the study area (see Appendix A at the end of this Section). For geologic units where sufficient shear-strength laboratory data could not be acquired, we applied the Hoek-Brown Failure Criterion (Hoek and others, 2002) to estimate the overall geologic unit strength.

The non-linear Hoek-Brown criterion is a rock mass characterization method which uses equations to relate rock mass classification through a Geological Strength Index (GSI) to the angle of internal friction of a rock mass. This method allows strength assessment based on collected data, mainly discontinuity density, discontinuity condition, and geologic material properties (Hoek and others, 2002; Marinos and others, 2007). The locations of rock and soil samples taken for shear testing and Hoek-Brown data collection locations within the study area are shown on Plate 1.3.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped based on average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength groups are summarized in Table 1.3. For each geologic strength group (Table 1.4) in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 1.3 and Table 1.4, and this map provides a spatial representation of material strength for use in the slope stability analysis.

As discussed later in this report, the criteria for earthquake-induced landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the Seismic Hazard Zone for earthquake-induced landslides. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map.

The strength characteristics of existing landslides (**Qls**) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available. We collect and compile primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. For the study area, strength parameters applicable to existing landslide planes were not available, so the strength parameter for existing landslides (**Qls**) is not included in this analysis.

Table 1.3. Summary of the shear strength statistics for the Contra Costa County portion of the Honker Bay Quadrangle.

HONKER BAY QUADRANGLE							
SHEAR STRENGTH GROUPS							
	Formation Name	**Number of Tests**	**Mean/Median Phi (deg)**	**Mean/Median Group Phi (deg)**	**Mean/Median Group C (psf)**	**No Data: Similar Lithology**	**Phi Values Used in Stability Analysis**
GROUP 1	**Plt**	**14**	**37 / 38**	**37 / 38**	**1225 / 1225**		**37**
GROUP 2	**Mnr**	**42**	**34 / 35**	**34 / 35**	**326 / 320**		**34**
GROUP 3	**Mc** **Emk**	**12** **34**	**32 / 34** **30 / 30**	**31 / 32**	**1051 / 825**		**31**
GROUP 4	**Pth** **Qh** **Qpf**	**29** **10** **4**	**28 / 28** **30 / 31** **30 / 30**	**29 / 28**	**493 / 500**	**af**	**28**
Emk includes Emkl and Emku; Qh includes Qhf, Qhsc, Qhbm; af includes af, alf, afbm							

Table 1.4. Summary of shear strength groups for the Contra Costa County portion of the Honker Bay Quadrangle.

SHEAR STRENGTH GROUPS FOR THE HONKER BAY QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
Plt	**Mnr**	**Emk** **Mc**	**Pth** **Qpf** **Qh**

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APPENDIX A: Sources of Rock Strength Data

SOURCE	NUMBER OF TESTS SELECTED
City of Pittsburg	7
Hoek Brown Data Collection	124
Antioch South Quadrangle	39
Brentwood Quadrangle	23
Clifton Court Forebay Quadrangle	23
Total Number of Shear Tests	216

SECTION 2: GROUND MOTION ASSESSMENT

for the

HONKER BAY 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

using the

2014 NATIONAL SEISMIC HAZARD MODEL

by

Rui Chen
P.G. 8598

DEPARTMENT OF CONSERVATION
CALIFORNIA GEOLOGICAL SURVEY

Purpose of this Section

This section of the Seismic Hazard Zone Report presents an assessment of shaking hazards from earthquakes in the Contra Costa County portion of the Honker Bay 7.5-Minute Quadrangle. It includes an explanation of the probabilistic seismic hazard analysis model from which ground motion parameters are derived, and how these parameters are used to delineate liquefaction and earthquake-induced landslide hazard zones in the study area.

PROBABILISTIC SEISMIC HAZARD ANALYSIS MODEL

Probabilistic ground motions are calculated using the United States Geological Survey (USGS) probabilistic seismic hazard analysis (PSHA) model for the 2014 Update of the National Seismic Hazard Maps (NSHMs) (Petersen and others, 2014; 2015). This model replaces ground-motion models of Petersen and others (2008), Frankel and others (2002), Cao and others (2003) and Petersen and others (1996) used in previous official Seismic Hazard Zone maps. Like previous models, the 2014 USGS PSHA model utilizes the best available science, models and data; and is the product of an extensive effort to obtain consensus within the scientific and engineering communities regarding earthquake sources and ground motions. In California, two earthquake source models control ground motion hazards, namely version three of the Uniform California Earthquake Rupture Forecast Model (UCERF3) (Field and others, 2013; 2014) and the Cascadia Subduction Zone model (Frankel and others, 2014). For shallow crustal earthquakes, ground motions are calculated using the Next Generation Attenuation Relations for Western U.S. (NGA-West2) developed from a Pacific Earthquake Engineering Research Center ground motion research project (Bozorgnia and others, 2014). The NGA-West2 includes five ground motion prediction equations (GMPEs): Abrahamson and others (2014), Boore and others (2014), Campbell and Bozorgnia (2014), Chiou and Youngs (2014), and Idriss (2014). For subduction zone earthquakes and earthquakes of other deep sources, GMPEs developed specifically for such sources are used, including the Atkinson and Boore (2003) global model, Zhao and others (2006), Atkinson and Macias (2009), and BC Hydro (Addo and others, 2012).

In PSHA, ground motion hazards from potential earthquakes of all magnitudes and distances on all potential seismic sources are integrated. GMPEs are used to calculate the shaking level from each earthquake based on earthquake magnitude, rupture distance, type of fault rupture (strike-slip, reverse, normal, or subduction), and other parameters such as time-average shear-wave velocity in the upper 30 m beneath a site (V_{S30}). In previous applications, a uniform firm-rock site condition was assumed in PSHA calculation and, in a separate post-PSHA step, National Earthquake Hazard Reduction Program (NEHRP) amplification factors were applied to adjust all sites to a uniform alluvial soil condition to approximately account for the effect of site condition on ground motion amplitude. In the current application, site effect is directly incorporated in PSHA via GMPE scaling. Specifically, V_{S30} is built into GMPEs as one of the repressors and, therefore, it is an input parameter in the PSHA calculation. V_{S30} value at each grid point is assigned based on a geology- and topography-based V_{S30} map for California developed by Wills and others (2015). The statewide V_{S30} map consists of fifteen V_{S30} groups with group mean V_{S30} values ranging from 176 m/s to 733 m/s. It is to be noted that these values are not determined from site-specific velocity data. Some group values have considerable uncertainties as indicated by a coefficient of variation ranging from 11% in Quaternary (Pleistocene) sand deposits to 55% in crystalline rocks.

For zoning purpose, ground motions are calculated at each grid point of a 0.005-degree grid (approximately 500-m spacing) that adequately covers the entire quadrangle. V_{S30} map and grid points in the Honker Bay Quadrangle are depicted in Plate 2.1. For site investigation, it is strongly recommended that V_{S30} be determined from site-specific shear wave velocity profile data.

PSHA provides more comprehensive characterizations of ground motion hazards compared to traditional scenario-based analysis by integrating hazards from all earthquakes above a certain magnitude threshold. However, many applications of seismic hazard analyses, including liquefaction and induced landslide hazard mapping analyses, still rely on scenario earthquakes or some aspects of scenario earthquakes. Deaggregation enables identification of the most significant scenario or scenarios in terms of magnitude and distance pair. Deaggregation is often performed for a particular site, a chosen ground motion parameter (such as peak ground acceleration or PGA), and a predefined exceedance probability level (i.e., hazard level). As in previous regulatory zone maps, the ground motion hazard level for liquefaction and landslide hazard zoning is 10% exceedance probability in 50 years or 475-year return period.

Probabilistic ground motion calculation and hazard deaggregation are performed using a new USGS hazard codebase, nshmp-haz version 1.1.6, a Java library developed in support of the USGS NSHM project. The Java code library is hosted in GitHub and is publicly available at: https://github.com/usgs/nshmp-haz/. This codebase also supports the USGS web-based site-specific ground motions calculator, the Unified Hazard Tool (https://earthquake.usgs.gov/hazards/interactive/). The source model used for the published 2014 NSHM is adopted in its entirety. The 2014 source model is also hosted in GitHub and is publically available at: https://github.com/usgs/nshmp-model-cous-2014/.

APPLICATION TO LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENT

The current CGS liquefaction hazard analysis approach requires that PGA be scaled by an earthquake magnitude weighting factor (MWF) to incorporate a magnitude-correlated duration effect (California Geological Survey, 2004; 2008). The MWF-scaled PGA is referred to as pseudo-PGA and is used as Liquefaction Opportunity (see Section 3 of this report). The MWF calculation is straight forward for a scenario earthquake. In PSHA, however, earthquakes of different magnitudes and distances contribute differently to the total hazard at a chosen probabilistic PGA level. The CGS approach to MWF calculation is based on binned magnitude-distance deaggregation. At each location, an MWF is calculated for each magnitude-distance bin and is weighted by the contribution of that magnitude-distance bin to the total hazard. The total MWF is the sum of probabilistic hazard-weighted MWFs from all magnitude-distance bins. This approach provides an improved estimate of liquefaction hazard in a probabilistic sense. All magnitudes contributing to the hazard estimate are used to weight the probabilistic calculation of PGA, effectively causing the cyclic stress ratio liquefaction threshold curves to be scaled probabilistically when computing factor of safety. This procedure ensures that large, distant earthquakes that occur less frequently but contribute *more*, and smaller, more frequent events that contribute *less* to the liquefaction hazard are appropriately accounted for (Real and others, 2000).

The current CGS landslide hazard analysis approach requires the probabilistic PGA and a predominant earthquake magnitude to estimate cumulative Newmark displacement for a given rock strength and slope gradient condition using a regression equation, described more fully in Section 4 of this report. The predominant earthquake magnitude is chosen to be the modal magnitude from deaggregation.

Pseudo-PGA and probabilistic PGA at grid points are depicted in Plates 2.2 and 2.3, respectively. Modal magnitude is depicted in Plate 4.4. The values of PGA and pseudo-PGA are higher in central and southwestern parts of the quadrangle, except in areas where there are hard Tertiary and crystalline rocks. Ground motion generally decreases toward the northeastern corner. Shaking hazards in the Honker Bay Quadrangle are controlled mainly by the Concord fault, with increasing contributions from the Great Valley fault zone toward the east and from the Green Valley fault in the northwest corner. Other fault sources that contribute to shaking hazards include the Calaveras fault, Hayward fault, Clayton fault, Franklin fault, and San Andreas fault. Background (gridded) seismicity also contributes to ground motion hazards. Modal magnitude (Plate 2.4) generally reflects the magnitudes of earthquakes that these contributing seismic sources are capable of producing. Ground motion distribution also is affected by subsurface geology. In general, expected PGA is higher where there are softer Quaternary sediments (lower V_{S30} values) and lower where there are harder Tertiary rocks (higher V_{S30} values). The table below summarizes ranges of PGA, pseudo PGA, modal magnitude, and V_{S30} values expected in the quadrangle.

Table 2.1. Summary of ground motion parameters used for liquefaction analyses.

PGA (g)	Pseudo-PGA (g)	Modal Magnitude	V_{S30} (m/s)
0.44 to 0.65	0.28 to 0.44	6.15 to 6.50	176 to 519

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SECTION 3: EVALUATION OF LIQUEFACTION HAZARD

in the

HONKER BAY 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

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Purpose of this Section

This Section of the Seismic Hazard Zone Report summarizes the analyses and criteria used to delineate liquefaction hazard zones in the Contra Costa County portion of the Honker Bay 7.5-Minute Quadrangle (study area).

ZONING TECHNIQUES

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. When this occurs, sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction, whereas liquefaction opportunity is a function of potential seismic ground shaking intensity.

The method applied in this study to evaluate liquefaction potential is similar to that Tinsley and others (1985) used to map liquefaction hazards in the Los Angeles region. These investigators, in turn, applied a combination of the techniques developed by Seed and others (1983) and Youd and Perkins (1978). California Geological Survey's (CGS's) method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates employing criteria adopted by the SMGB (CGS, 2004).

Liquefaction Susceptibility

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, density, compaction, cementation, saturation, and depth from the surface govern the degree of resistance to liquefaction. Some of these properties can be correlated to a deposit's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment.

Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may, however, be vulnerable to strength loss with remolding and represent a hazard that is not specifically addressed in this investigation. Soil characteristics that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. In summary, soils that lack resistance (susceptible soils) typically are saturated, loose, and granular. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's inventory of areas containing soils susceptible to liquefaction begins with evaluation of historical occurrences of liquefaction, geologic maps, cross-sections, geotechnical test data, geomorphology, and groundwater hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historic-high depths to groundwater, are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on observable characteristics of surficial deposits, liquefaction susceptibility maps are often similar to Quaternary geologic maps, varying depending on local groundwater levels. Generalized correlations between susceptibility, geologic map unit, and depth to ground water are summarized in Table 3.1.

Table 3.1. Liquefaction susceptibility of Quaternary units in the Contra Costa County portion of the Honker Bay Quadrangle.

Geologic Map Unit	Liquefaction Susceptibility*
Qpf	Low to Very Low
Qhf	Moderate
Qhsc	High to Very High
Qhbm	Moderate to High
af	Variable
*When saturated	

Ground Motion for Liquefaction Hazard Assessment

Ground motion calculations used by CGS for regional liquefaction zonation assessments are based on the probabilistic seismic hazard analysis (PSHA) model developed by USGS (Petersen and others, 2014; 2015) for the 2014 Update of the United States National Seismic Hazard Maps (NSHMs). The model calculates ground motion in terms of peak horizontal ground acceleration (PGA) at a 10 percent in 50 years exceedance probability level. For liquefaction analysis, CGS modifies probabilistic PGA by a scaling factor that is a function of magnitude. Calculation of the scaling factor is based on binned magnitude-distance deaggregation of seismic source contribution to total shaking. The result is a magnitude-weighted, pseudo-PGA that CGS refers to as Liquefaction Opportunity (LOP). This approach provides an improved estimate of liquefaction hazard in a probabilistic sense, ensuring that the effects of large, infrequent, distant earthquakes, as well as smaller, more frequent, nearby events are appropriately accounted for (Real and others, 2000). These LOP values are then used to calculate cyclic stress ratio (CSR), the seismic load imposed on a soil column at a particular site. A more detailed description of the development of ground shaking opportunity data and parameters used in liquefaction hazard zoning can be found in Section 2 of this report.

Liquefaction Analysis

As mentioned in the Engineering Geology section of this report, borehole logs containing useful geotechnical information were found during the course of this study. However, when borehole logs with adequate geotechnical soil-test data are available, CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997; Youd and others, 2001). The procedure first calculates the resistance to liquefaction of each soil layer penetrated at a test-drilling site, expressed in terms of cyclic resistance ratio (CRR). The calculations are based on standard penetration test (SPT) results, groundwater level, soil density, grain-size analysis, moisture content, soil type, and sample depth. The procedure then estimates the factor of safety relative to liquefaction hazard for each of the soil layers logged at the site by dividing their calculated CRR by the pseudo PGA-derived CSR described in the previous section.

CGS uses a factor of safety (FS) of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil layers. The liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test, using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of all the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. In addition to FS, consideration is given to the proximity to stream channels, which accounts in a general way for factors such as sloping ground or free faces that may influence the severity of liquefaction-related ground deformation.

Liquefaction Zoning Criteria

Areas underlain by materials potentially subject to liquefaction during an earthquake are included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (CGS, 2004). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1) Areas known to have experienced liquefaction during historical earthquakes
2) All areas of uncompacted artificial fill that are saturated, nearly saturated, or may be expected to become saturated
3) Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4) Areas where existing subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:

    a. Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the anticipated depth to saturated soil is less than 40 feet; or

    b. Areas containing soil deposits of Holocene age (less than 11,700 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or

    c. Areas containing soil deposits of latest Pleistocene age (11,700 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

Application of the above criteria allows compilation of Earthquake Zones of Required Investigation for liquefaction hazard, which are useful for preliminary evaluations, general land-use planning and delineation of other special study zones (Youd, 1991).

Delineation of Liquefaction Hazard Zones

Following the liquefaction analysis for the study area, CGS applied the liquefaction zoning criteria to the evaluation to determine the liquefaction hazard zones. Based on the evaluation, approximately 25 square kilometers (10 square miles) of land in the study area has been designated as EZRI for liquefaction. These zones are mainly located in lowlands adjacent to the San Joaquin River and New York Slough, within Browns and Winter Island. Additionally, liquefaction encompass major stream valleys such as Mount Diablo Creek, Willow Creek, Kirker Creek, and other smaller unnamed stream valleys. Minor drainages that ultimately outlet into the San Joaquin River and Suisun Bay are also zoned.

The following is a detailed description of each of the zoning criteria that governed the construction of the EZRI for liquefaction for the study area.

Areas of Past Liquefaction

Documented observations of historical liquefaction are not recorded for the study area, nor has evidence of paleoseismic liquefaction been reported.

Artificial Fills

Artificial fill in the study area are significant enough to depict at the scale of mapping (1:24,000), and include engineered and non-engineered material. Engineered fills are typically placed on firm and unyielding foundation soils or bedrock determined by field testing and observations. These materials are mechanically moisture conditioned, placed in defined loose-lift thicknesses, and compacted using prescribed methods. Engineered fill typically meet relative compaction requirements as determined by prescribed methods such as American Society for Testing and Materials (ASTM) methods. Examples of engineered fills in the study area include grading associated with Highway 4; Atchison-Topeka and Santa Fe, Southern Pacific, and BART railways; and the Contra Costa Canal. Non-engineered fills include materials where documentation regarding placement and compaction are not available and these materials are conservatively assumed to be relatively loose and uncompacted. Examples of non-engineered fills in the study area include hillside grading for residential development and grading associated with facilities located on or adjacent to the San Joaquin River and New York Slough.

Areas with Sufficient Existing Geotechnical Data

Geologic classification and material testing data for over 450 borehole logs are used to quantitatively analyze liquefaction potential in the study area. These boreholes indicate a high potential for liquefaction of young Quaternary sedimentary deposits and indicate a low potential for liquefaction of older Quaternary deposits, which is characteristic of Pleistocene sediments.

Areas with Insufficient Existing Geotechnical Data

Where borehole logs and associated geologic classification and material testing data are not sufficient to quantitively analyze the potential for liquefaction in the study area, more generalized criteria are used. In general, the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g for the study area. Based on the consistent levels of ground shaking across the site, the age of the Quaternary sedimentary deposits and historic-high depth to groundwater are used to delineate liquefication zones with insufficient existing geotechnical data.

Areas mapped as Late Pleistocene to modern soils, with the anticipated depth to saturated soil of less than 40 feet, are included in the liquefaction zone. Additionally, Pleistocene soils, with anticipated depth to saturated soil of less than 20 feet, are included in the liquefaction zone.

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SECTION 4: EVALUATION OF EARTHQUAKE-INDUCED LANDSLIDE HAZARD

in the

HONKER BAY 7.5-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

by

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Purpose of this Section

This Section of the Seismic Hazard Zone Report summarizes the analyses and criteria used to delineate earthquake-induced landslide hazard zones in the Contra Costa County portion of the Honker Bay 7.5-Minute Quadrangle (study area).

ZONING TECHNIQUES

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method as originally implemented analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. The double integration of the earthquake acceleration recording to derive displacement considers only accelerations above a threshold value that represents the inertial force required to initiate slope movement (Factor of Safety = 1). This threshold value, called the “yield acceleration,” is a function of the strength of the earth materials and the slope gradient, and therefore represents the susceptibility of a given area to earthquake-induced slope failure.

As implemented for the preparation of earthquake-induced landslide zones, susceptibility is derived by combining a geologic map modified to reflect material strength estimates with a slope gradient map. Ground motion parameters are calculated using the United States Geological Survey (USGS) National Seismic Hazard Model, and Newmark displacements are estimated from a regression equation developed by Jibson (2007) that uses susceptibility and ground motion parameters. Displacement thresholds that define earthquake-induced hazard zones are from McCrink and Real (1996) and McCrink (2001).

Earthquake-Induced Landslide Susceptibility

Earthquake-induced landslide susceptibility, defined here as Newmark’s yield acceleration (1965), is a function of the Factor of Safety (FS) and the slope gradient. To derive a Factor of Safety, an infinite-slope failure model under unsaturated slope conditions was assumed. In addition, material strength is characterized by the angle of internal friction (Φ) and cohesion is ignored. As a result of these simplifying assumptions, the calculation of FS becomes

$$FS = \frac{\tan \Phi}{\tan \beta}$$

where **β** is the slope gradient. The yield acceleration (a_y) is then calculated from Newmark's equation:

$$a_y = (FS - 1) g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and **α** is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure **α** is the same as the slope gradient angle **(β)**.

These calculations are conducted on a GIS by converting the vector (lines, points and polygons) digital geologic map to a raster (regular spaced grid) material strength map that contains the Φ values assigned to the mapped geologic units (Table 1.3). Preparation of a slope gradient (**β**) map is discussed in Section 1.

Ground Motion for Landslide Hazard Assessment

Ground motion calculations used by CGS for regional earthquake-induced landslide zonation assessments are currently based on the USGS probabilistic seismic hazard analysis (PSHA) model for the 2014 Update of the United States National Seismic Hazard Maps (Petersen and others, 2014; 2015). The model is set to calculate ground motion hazard in terms of peak horizontal ground acceleration (PGA) at a 10 percent in 50 years exceedance probability level. Raster versions of the PSHA PGA and Modal Magnitude maps for the Honker Bay 7.5-Minute Quadrangle were calculated from the statewide model and applied in the Newmark displacement calculations, as described below. A more detailed description of the development of ground motion parameters used in preparation of the Seismic Hazard Zone for earthquake-induced landslides can be found in Section 2 of this report.

Earthquake-Induced Landslide Hazard Potential

Earthquake-induced landslide hazard potential is derived by combining the susceptibility map (a_y) with the ground motion maps (PGA and Modal Magnitude) to estimate the amount of permanent displacement that a modeled slope might experience. The permanent slope displacement is estimated using a regression equation developed by Jibson (2007). That equation is:

$$\log D_N = -2.710 + \log\left[\left(1 - \frac{a_y}{PGA}\right)^{2.335} \left(\frac{a_y}{PGA}\right)^{-1.478}\right] + 0.424\boldsymbol{M} \pm 0.454$$

where D_N is Newmark displacement and **M** is magnitude. Jibson's (2007) nomenclature for yield acceleration (a_c) and peak ground acceleration (a_{max}) have been replaced here by a_y and PGA, respectively, to be consistent with the nomenclature used in this report.

The above equation was applied using a_y, PGA and Modal Magnitude maps as input, resulting in mean values of Newmark displacement at each grid cell (the standard deviation term at the end of the equation is ignored). The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001).

Earthquake-Induced Landslides Zoning Criteria

Seismic Hazard Zones for earthquake-induced landslides were delineated using criteria adopted by the California State Mining and Geology Board (CGS, 2004). Under these criteria, these zones are defined as areas that meet one or both of the following conditions:

1) Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.
2) Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Delineation of Earthquake-Induced Landslide Hazard Zones

Upon completion of the earthquake-induced landslide hazard evaluation within the study area, CGS applied the above criteria to its findings in order to delineate Earthquake Zones of Required Investigation for earthquake-induced landslides. Based on the evaluation, about 4 square kilometers (2 square miles) of the study area are included in the Seismic Hazard Zone for landslides. These zones are prominent on the side slopes of many moderate to steep ridges and generally increase in size towards the south-central part of the study area. Following is a description of the criteria-based factors that governed the construction of the Seismic Hazard Zone Map for the study area.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the Seismic

Hazard Zone. Mapping and categorization of existing landslides is discussed in further detail in Section 1.

Hazard Potential Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), the Seismic Hazard Zone for earthquake-induced landslides encompass all areas that have calculated Newmark displacements of 5 centimeters or greater.

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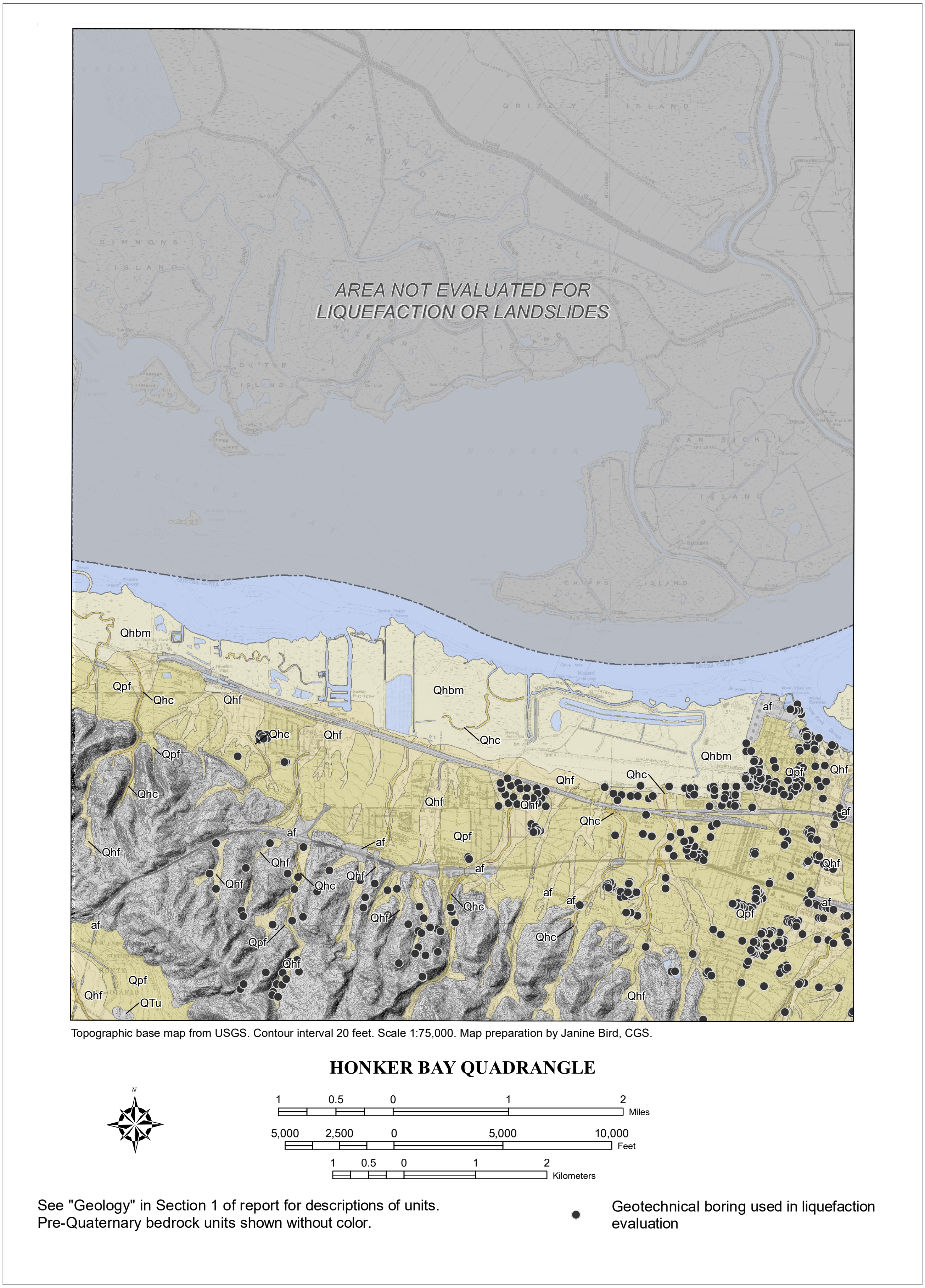
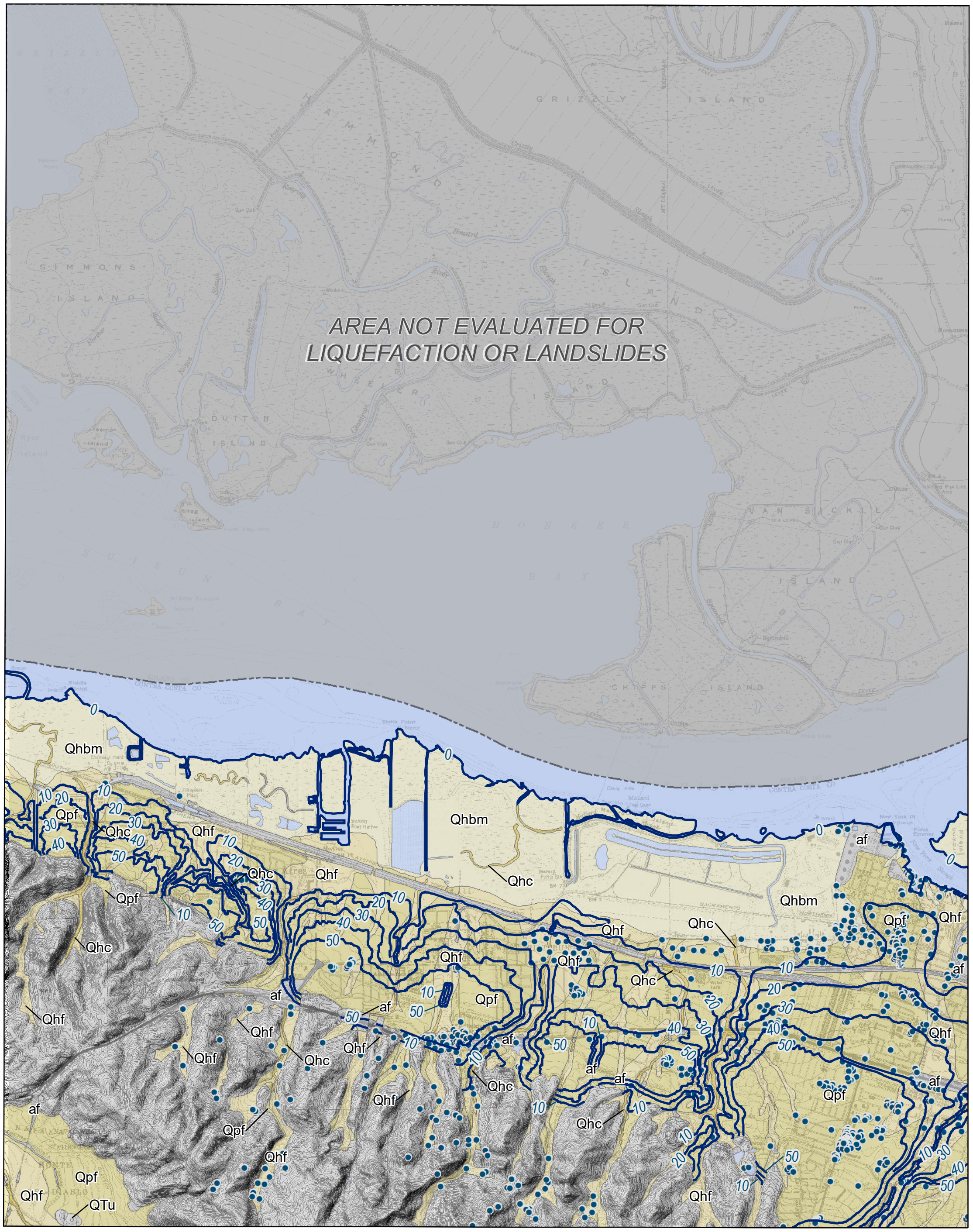


Plate 1.1 Quaternary geologic materials map and locations of boreholes used in evaluating liquefaction hazard, Honker Bay Quadrangle, California.



Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. Map preparation by Janine Bird, CGS.

HONKER BAY QUADRANGLE

N

1 0.5 0 1 2 Miles

4,900 2,450 0 4,900 9,800 Feet

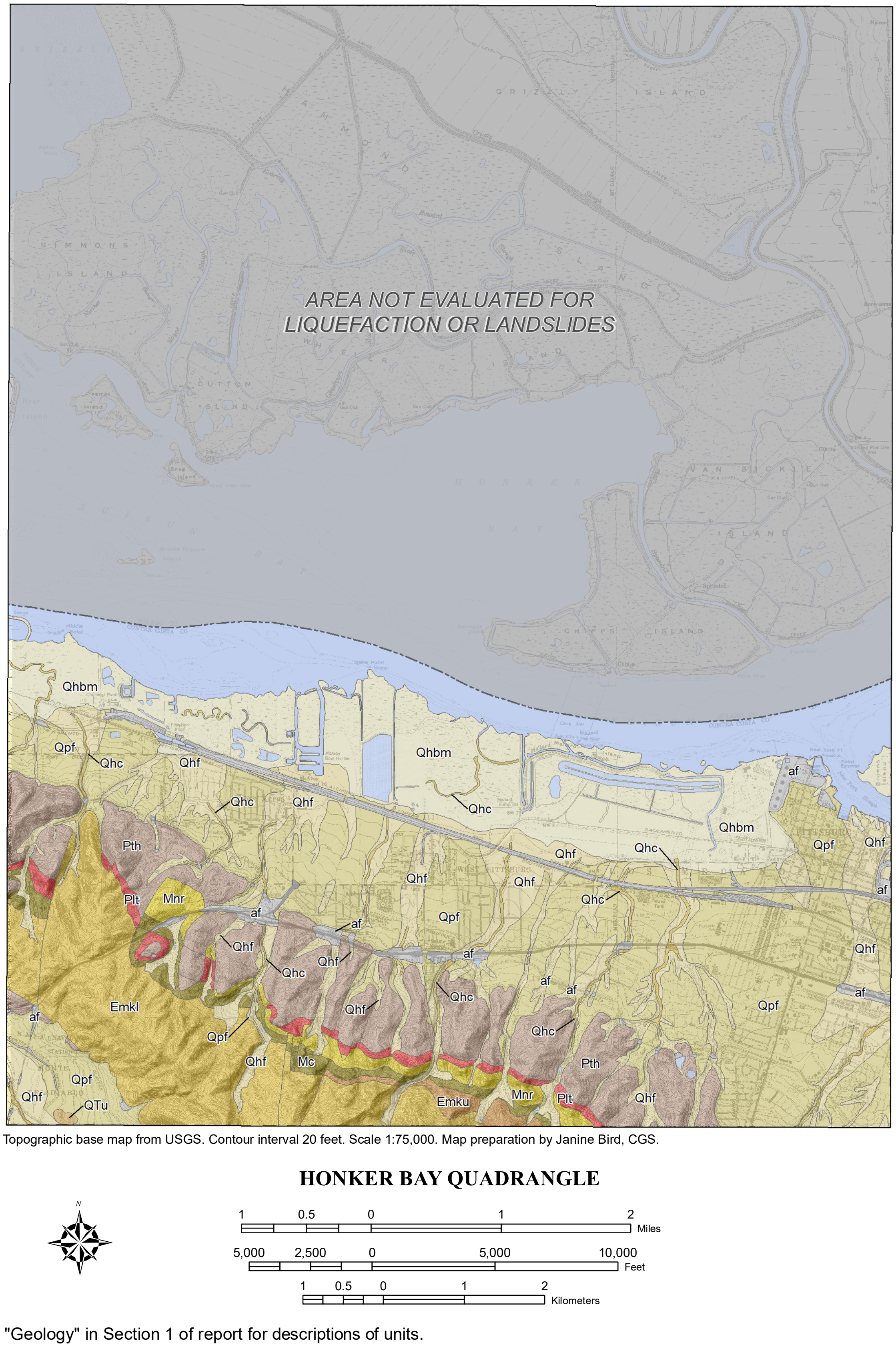
1 0.5 0 1 2 Kilometers

See "Geology" in Section 1 of report for descriptions of units.
Pre-Quaternary bedrock units shown without color.

Groundwater measurement location

10 Depth to groundwater (in feet)

Plate 1.2 Depth to historic-high groundwater levels in Quaternary alluvial deposits and ground water data points, Honker Bay Quadrangle, California.



Topographic base map from USGS. Contour interval 20 feet. Scale 1:75,000. Map preparation by Janine Bird, CGS.

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See "Geology" in Section 1 of report for descriptions of units.

Plate 1.3 Geologic materials map, Honker Bay Quadrangle, California.

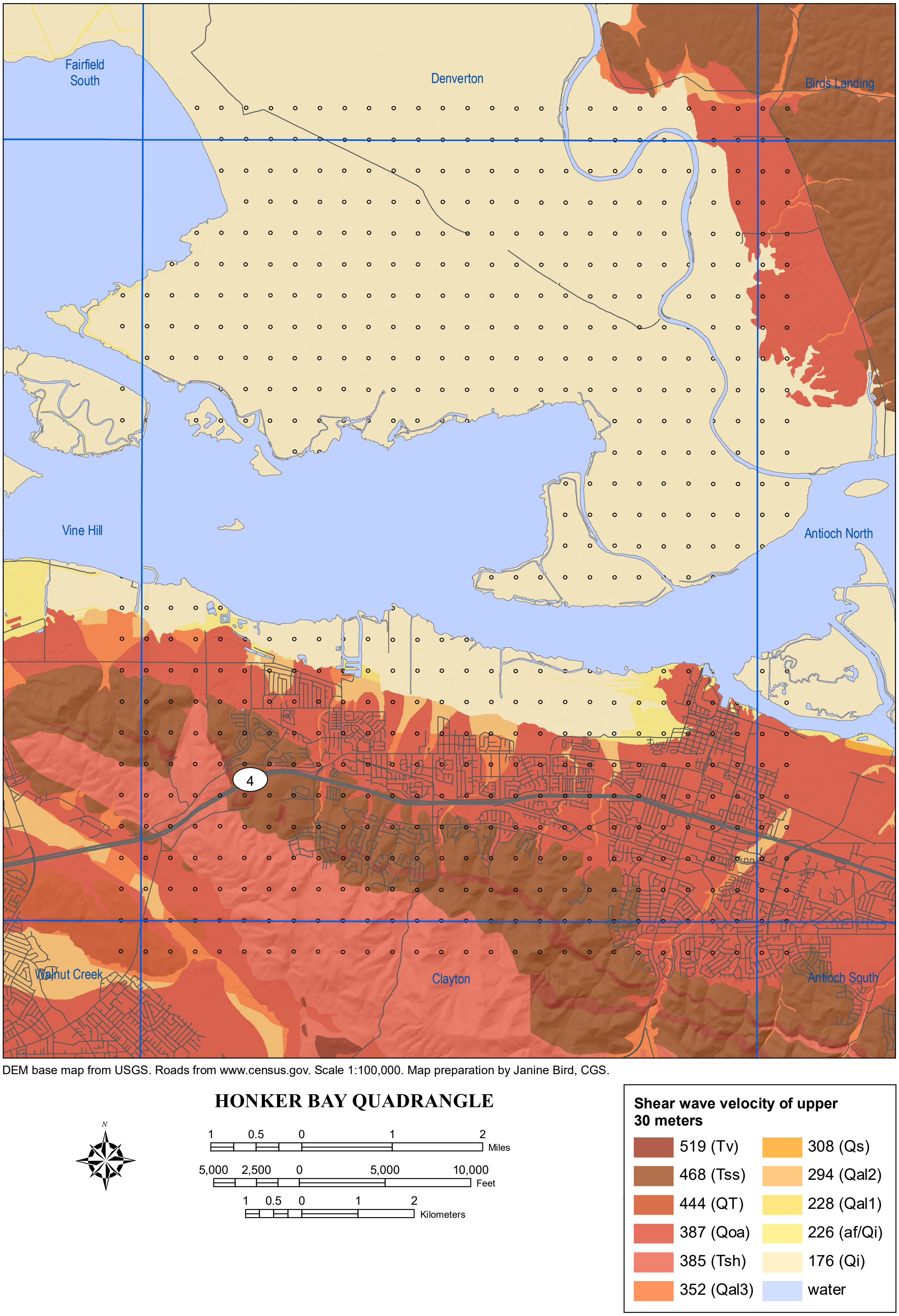

Plate 2.1 Map of Vs30 groups and corresponding geologic units extracted from the state-wide Vs30 map developed by Wills and others (2015), Honker Bay Quadrangle and surrounding area, California.

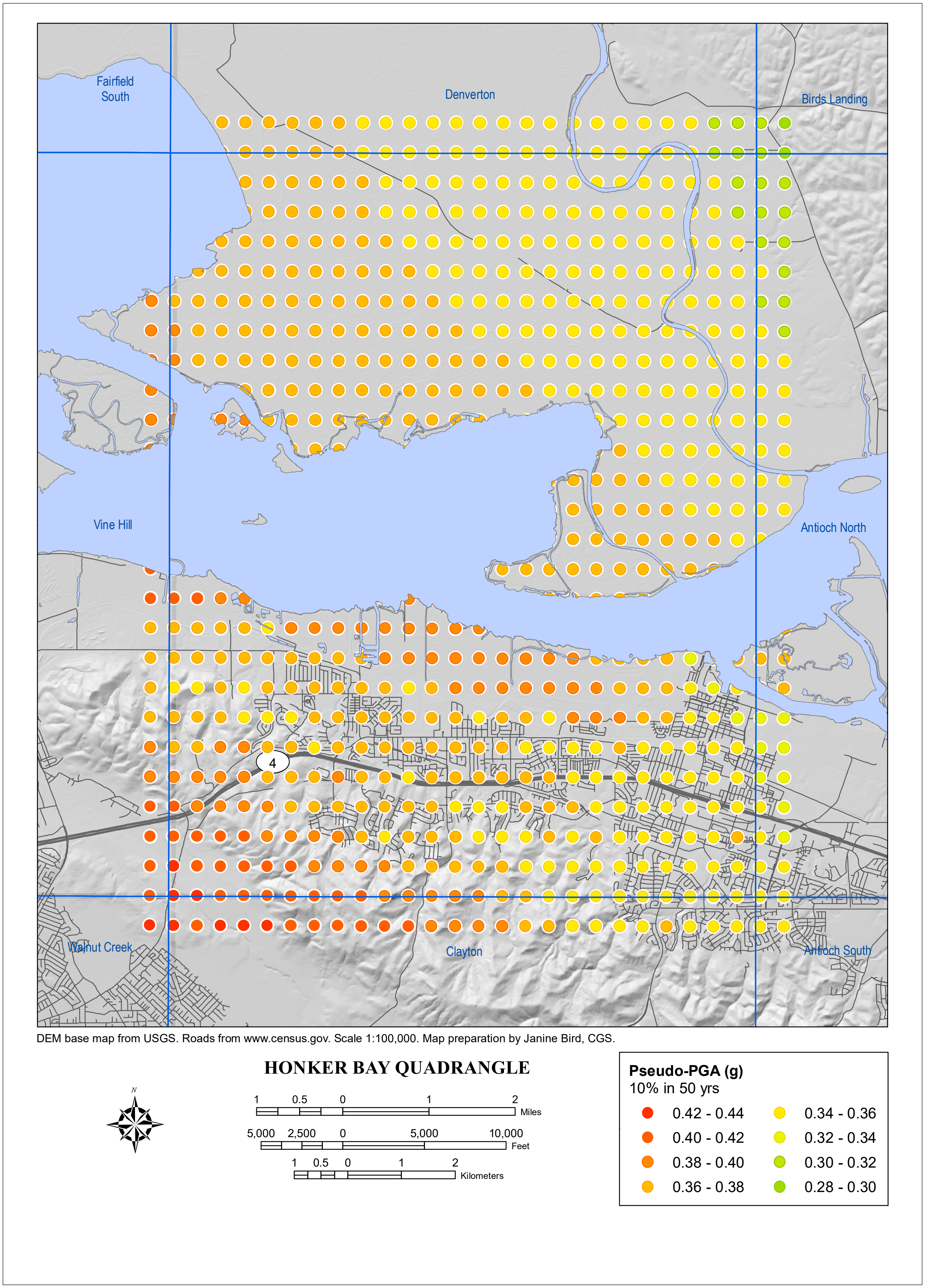

Plate 2.2 Pseudo-PGA for liquefaction hazard mapping analysis, Honker Bay Quadrangle and surrounding area, California.

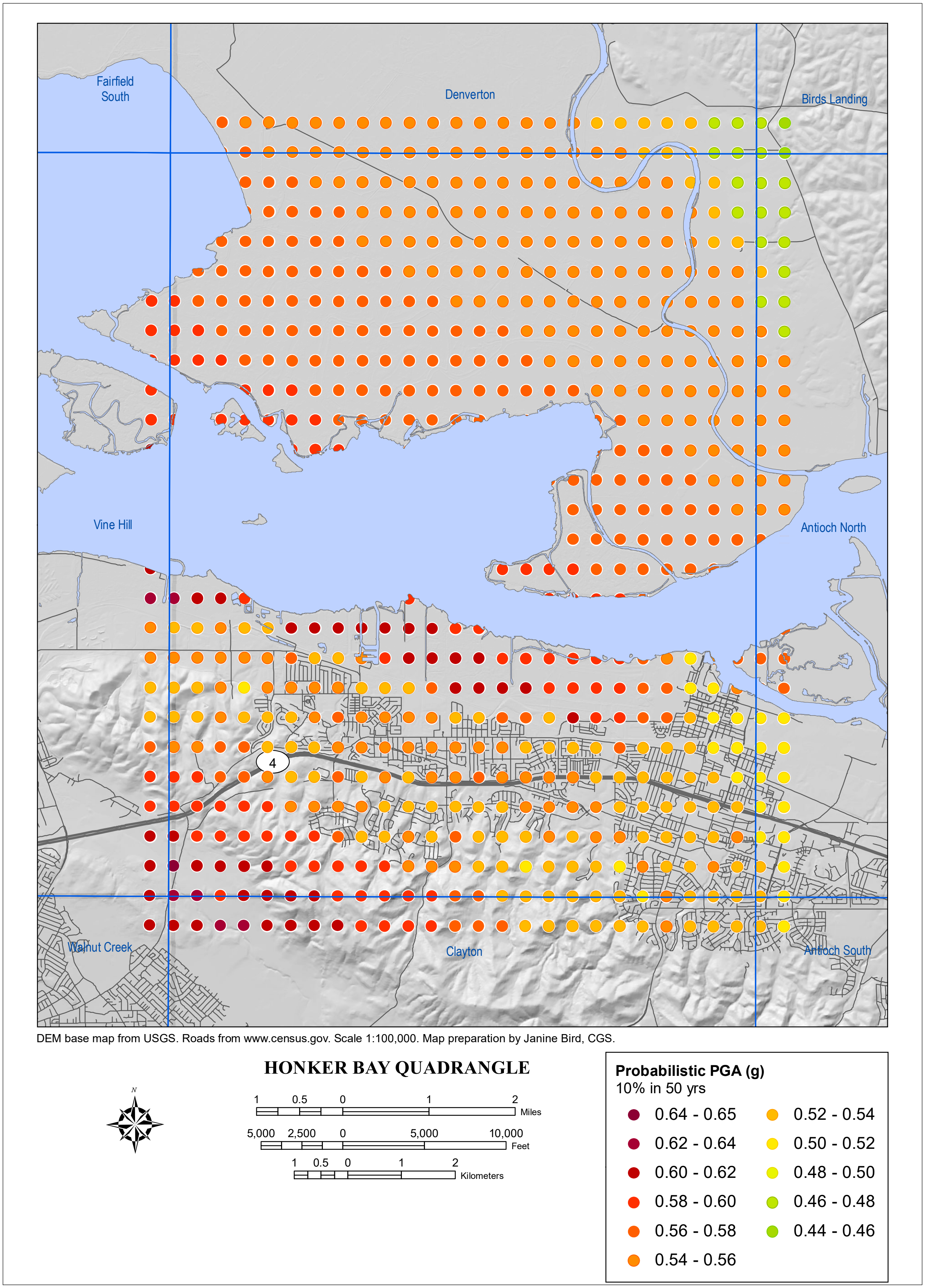

Plate 2.3 Probabilistic peak ground acceleration for landslide hazard mapping analysis, Honker Bay Quadrangle and surrounding area, California.

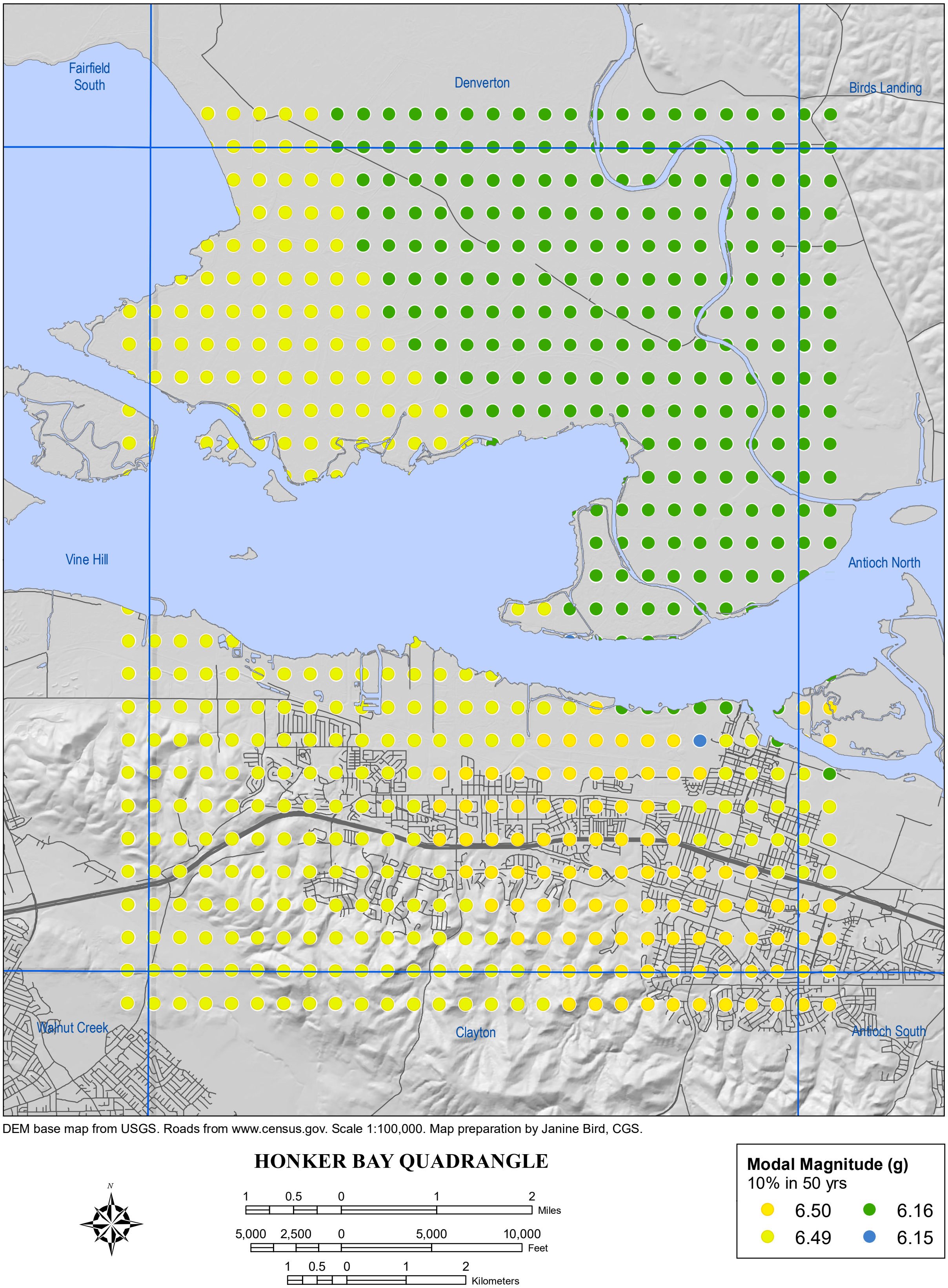

Plate 2.4 Modal magnitude for landslide hazard mapping analysis, Honker Bay Quadrangle and surrounding area, California.